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Liquefaction Analysis of Bridge Foundation in Kurigram

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Abstract

A place with a high propensity for liquefaction may experience greater destruction due to earthquakes since liquefaction can magnify its effects. This study focuses on assessing the seismic hazard potential and liquefaction susceptibility of the Sonahat Bridge over the Dudhkumar River in Kurigram, Bangladesh. The region, bordering the Indo-Burma Folded Belt, Himalayan Syntaxis and the Dauki Fault, has a historical record of significant earthquakes. Assessing seismic risks becomes imperative for effective hazard management in areas of rapid economic growth. To evaluate the liquefaction potential, the study employs the factors of safety against liquefaction (F_L) and the corresponding liquefaction potential index (LPI) which is a widely used hazard assessment index. The LPI values are calculated for different earthquake magnitudes, ranging from Mw 5.5 to 8, with a peak horizontal ground acceleration (PGA) of 0.36 g. Data from four Standard Penetration Test (SPT) boreholes are utilized for the analysis. Based on the SPT-N values obtained from each borehole, the LPI values are determined for the soil profile at the Sonahat Bridge site. The results reveal varying LPI values, ranging from 21.5 to 45.37, indicating diverse liquefaction potential across the area. The results provide valuable insights into the potential liquefaction hazards, aiding in informed decision-making regarding land-use planning, infrastructure design and construction practices.

Keywords: *Earthquake; Liquefaction; Standard penetration test (SPT); Simplified procedure; Liquefaction potential index (LPI).*

1 Introduction

Liquefaction analysis is a process of evaluating the potential for soil liquefaction during seismic events. The liquefaction potential index (LPI) is a widely used parameter for evaluating the potential for soil liquefaction. It is a single-valued parameter that quantifies the severity of liquefaction and predicts surface manifestations of liquefaction damage or failure potential of a liquefaction prone area. Quick loading during seismic occurrences raises pore-water pressure, transforming granular minerals from solid to liquid, reducing soil strength. Understanding liquefaction is vital for assessing ground failure risk and guiding engineering and hazard management. The liquefaction potential index (LPI), which depends on the magnitude of the peak horizontal ground acceleration, provides an integration of liquefaction potential over the depth of a soil profile and forecasts the performance of the entire soil.

The test procedures for measuring soil liquefaction characteristics were presented by (Seed and Idriss, 1971). Many researchers have modified and improved their proposed simplified procedure over time (Youd and Idriss, 2001), and (Cetin et al., 2004). However, liquefaction potential had been evaluated based on the field SPT data by (Seed et al., 1983). (Muley et al., 2015) collected sand samples from 5 locations in the Roorkee region and SPT-N values with depths up to 8m to calculate liquefaction potential. (Rahman et al., 2015) estimated liquefaction potential from 23 boreholes having a 21m drilling depth in Dhaka city and 19 Nos boreholes were marked as severe liquefaction potentiality. (Ansari et al., 2018) collected SPT-N values from 114 Nos. boreholes in different locations of Dhaka city to evaluate the liquefaction potential index using a simplified procedure. About 74% of locations exhibited high to very high liquefaction potentiality. (Hossain et al., 2020) analysed the liquefaction potential in Moulavibazar town from 25 Nos. boreholes. Among the boreholes, 17 Nos. boreholes were identified as very high liquefaction susceptibility.

In Bangladesh, the loose and soft Quaternary sediments cover over 80% of the country's land area. Following the 1885 Bengal Earthquake, the 1897 Great Indian Earthquake and the 1918 Srimangal Earthquake, extensive liquefaction phenomena were observed in Bangladesh's alluvial deposits. A series of seismic events along the Dauki fault are believed to be the cause of the liquefaction phenomena which were identified in the northern and northeastern regions of the country as a result of paleoseismic investigations. This area may experience an earthquake of a moderate to large size due to ongoing tectonic deformation along the active Indo-Burman plate-boundary faults. Given its proximity to the two potential earthquake sources, the Indo-Burma Fold Belt and the Dauki Fault, Bangladesh's northeast is the area most at risk.

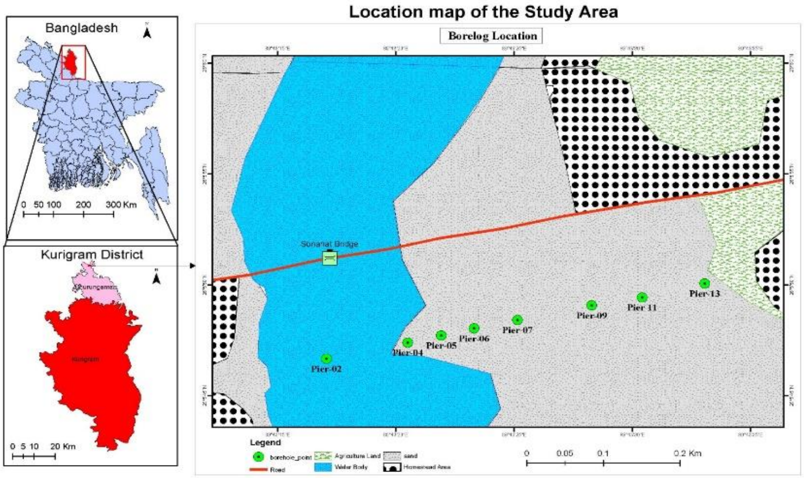


Figure 1. Location map of the study area.

For the purposes of the future urban growth and planning, the liquefaction potential of Kurigram, a district town in the northeastern region of the country that is expanding quickly, has been assessed in the current study. This town is located in the most seismically hazardous area in Bangladesh. The Holo-Pleistocene and Holocene loose and mushy sediments make up the underlying soils of the town down to a depth of more than 20m.

2 Study Area

The Sonahat Bridge is situated between 26°05'49"N and 89°43'13"E over the Dudhkumar River in Kurigram, Bangladesh. Kurigram District is situated in northern region of Bangladesh along's the country's border with India. Kurigram town lies on the Rangpur Shaddle as per local geology, bordered by the Assam Basin to the north and the center of the Shillong Massif to the east. The active Dauki fault runs southward, nearby the study area. In accordance with the Bangladesh National Building Code (BNBC 2020), seismic zones have been categorized based on peak horizontal ground acceleration (PGA), where Kurigram Town is located in Zone IV, the most seismically sensitive zone with a PGA value of 0.36 g. Details of locations of sites are shown in Table 1.

Table 1. Location of Sites in Sonahat Bridge, Kurigram, Bangladesh

Sample No	Name of Sites	Bore Hole Depth (m)	Location
1	P-11	21.00	26°05'46"N and 89°43'17"E
2	P-09	21.00	26°05'47"N and 89°43'22"E
3	P-07	21.00	26°05'48"N and 89°43'26"E
4	P-06	21.00	26°05'50"N and 89°43'30"E

3 Methodology

The standard penetration test blow counts (SPT-N) are used globally for assessing liquefaction potential during design earthquakes. In this study, SPT-N values were collected at 1.5 m intervals, starting from 1.5 m depth and extending to 21 m depth. This data was utilized to calculate the factor of safety against liquefaction (F_L) and the liquefaction potential index (LPI) for each interval, aiming to gauge the liquefaction severity at each borehole site.

Four boreholes were examined, and SPT-N values, as well as disturbed samples, were gathered at 1.5 m intervals down to 21 m depth. Boring site selection was informed by the area's surface geological units, and their positions are indicated on the surface geological map Figure 1. Unified Soil Classification System (USCS) was employed to classify subsoils down to 21 m depth in each borehole. The groundwater level at each borehole was recorded after 24 h from the completion of the borehole and topographic elevation was also recorded during the site investigation. The grain size distribution data are obtained by mechanical sieve analysis of coarse-grained soils and hydrometer analysis of fine-grained soils to determine the percentages of silt and clay. The groundwater level varies from 0.013 m to 3.5 m in the boreholes of the study area. For the liquifaction analysis, the ground water table assumed at ground level.

3.1 Calculation of factor of safety (FS) and Liquifaction Potential Index (LPI)

According to the Simplified Procedure of liquefaction resistance estimation proposed by Seed and Idriss (1971), the cyclic stress ratio (CSR) is compared to the liquefaction resistance of the soil represented by the cyclic resistance ratio (CRR) for $M_w = 7.5$ earthquakes (i.e., $CRR_{7.5}$). A magnitude scaling factor (MSF) is used for other earthquake magnitudes to adjust $CRR_{7.5}$ to determine the CRR. The factor of safety (F_L) against liquefaction is defined in terms of the CRR, CSR, and MSF as follows:

$F_L = MSF \times \frac{CRR7.5}{CSR}$ (1)

$MSF = 6.9 \times \exp(\frac{-M}{4})-0.058, MSF \leq 1.8$ (2)

$CSR=0.65\times (\frac{a_{max}}{g}) \times (\frac{\sigma_t}{\sigma_{te}}) \times r_d$ (3)

r_d = stress reduction factor, $r_d = \frac{1-0.4113z^2+0.04052z+0.001753z^{1.5}}{1-0.4177z^{0.5}+0.05729z-0.006205z^{1.5}+0.001210z^2}$ (4)

here “z” is the depth

$CRR_{7.5}= \frac{1}{34-(N_1)_{60cs}} + \frac{(N_1)_{60cs}}{135} + \frac{50}{[10(N_1)_{60cs}+45^2]^2} - \frac{1}{200}$ (5)

$(N_1)_{60cs}=\alpha+\beta(N_1)_{60}$ (6)

α and β both depends on Fine contents of subsoil.

$\alpha= 0$ for $FC \leq 5\%$ (6a)

$\alpha=\exp [1.76 - \frac{190}{FC^2}]$ for $5\%<FC<35\%$ (6b)

$\alpha= 5$ for $FC \geq 35\%$ (6c)

$\beta= 1$ for $FC \leq 35\%$ (6d)

$\beta= \exp [0.99 + \frac{FC^{1.5}}{1000}]$ for $5\%<FC<35\%$ (6e)

$\beta= 1.2$ for $FC \leq 35\%$ (6f)

$(N_1)_{60}=N_m C_N C_E C_B C_R C_S$ (7)

N_{spt} = Field SPT-N value

$C_N = (\frac{P_a}{\sigma_{te}})^{0.5}$ (8)

where Pa = 100, because C_N normalizes N_m to an effective overburden pressure of about 100 kPa.

$LPI = \int_0^{20} F(z)\,(z)\,dz$ (9)

$F(z) = 1 - F_L \; for \; F_L < 1.0$ (9a)

$F(z) = 0 \; for \; F_L \geq 1.0$ (9b)

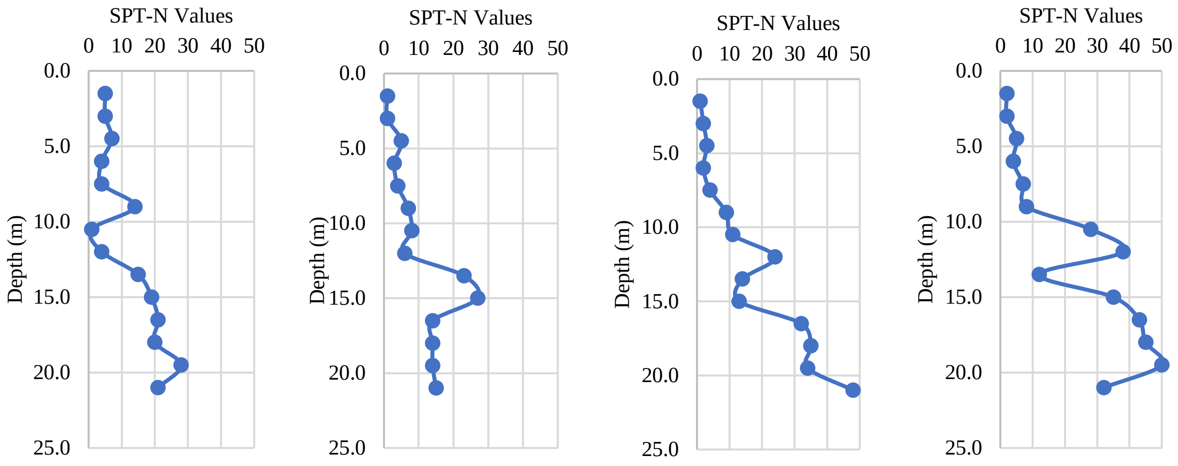
$W(z) = 10 - 0.5z \; for \; z < 20m$ (9c)

$W(z) = 0 \; for \; z > 20m$ (9d)

Where z is the depth from the ground surface in meters. The level of liquifaction severity with respect to LPI as per (Iwasaki et al., 1982), (Luna and Frost, 1998), and (MERM, 2003) is given in Table 2.

Table 2. Level of Liquifaction severity

LPI value	(Iwasaki et al., 1982)	(Luna and Frost, 1998)	(MERM, 2003)
LP= 0	Very Low	Little to none	None
0<LPI<5	Low	Minor	Low
5<LPI<15	High	Moderate	Medium
15<LPI	Very High	Major	High



(a) P-11 (b) P-09 (c) P-07 (d) P-06

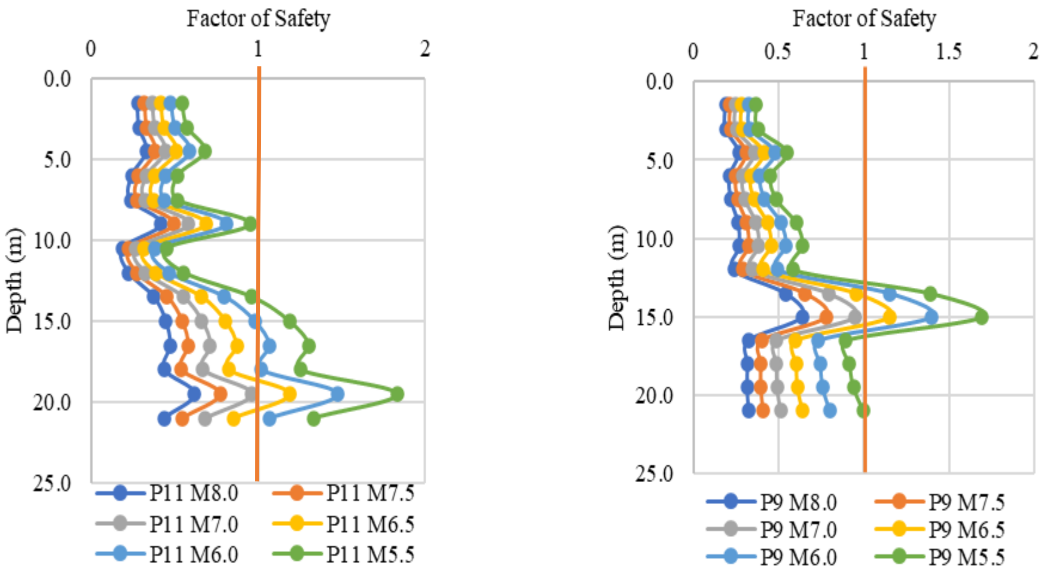
Figure 2. SPT-N values with the depth at different locations.

4 Results and Discussion

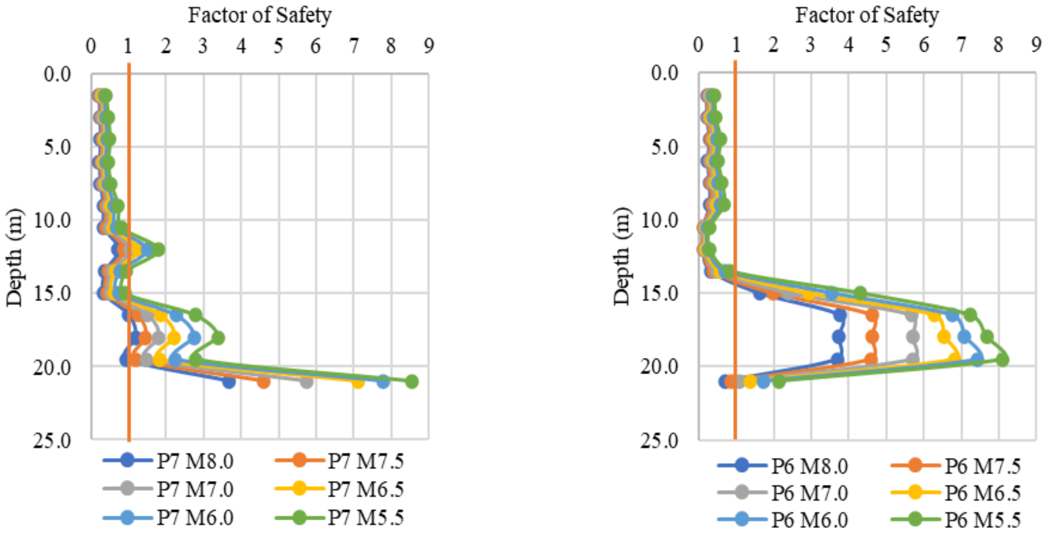
This study focuses on the critical assessment of bridge foundation safety by evaluating the factors of safety against liquefaction (F_L) and the corresponding liquefaction potential indices (LPI). The analysis is carried out for the worst seismic scenario along the bridge alignment, utilizing a simplified approach based on Standard Penetration Test (SPT) data. Figure 2 presents the variation of SPT-N values with depth in the bore logs.

4.1 Factor of Safety against Liquifaction

The liquifaction potential for the study area has been evaluated for four different locations for earthquake magnitude Mw 5.5, 6.0, 6.5, 7.0, 7.5 & 8.0 with the PGA 0.36g.



(a) P-11 (b) P-09



(c) P-07

(d) P-06

Figure 3. Factor of Safety against the depth at different locations.

From the Figure 3, the Factor of Safety vs depth according to different magnitude of the earth quake have been depicted. The analysis of the Factor of Safety (F_L) reveals the important insights regarding the liquefaction potential at different depths in the study area. Up to a depth of 15 meters from the ground surface, the F_L values for various earthquake magnitudes are consistently less than 1. This outcomes indicate a clear susceptibility to liquefaction in this shallow layer.

The study highlights that beyond 15 meters depth, the Factor of Safety (F_L) values fluctuate due to variations in SPT-N values. For certain samples, F_L drops below 1, indicating susceptibility to severe earthquakes. However, sample P7 exhibits stability against liquefaction below 15 meters. Understanding the depth variations and SPT-N values is crucial for assessing liquefaction potential and implementing the appropriate mitigation measures in earthquake-prone regions.

4.2 Liquifaction Potential Index

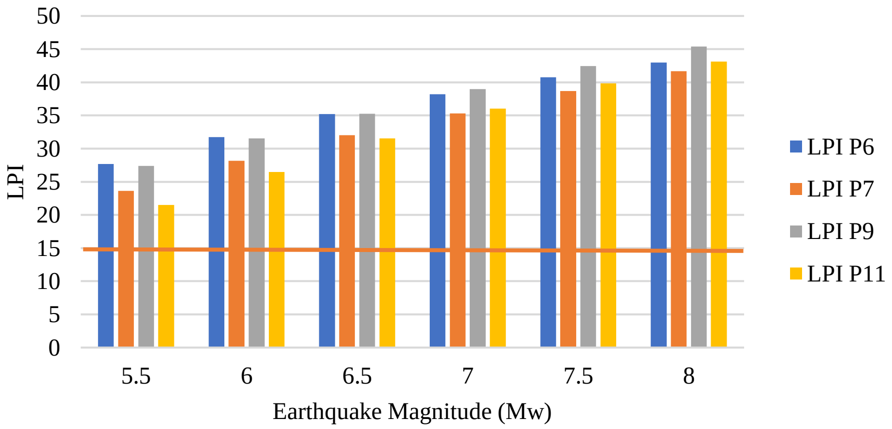


Figure 4. Factor of Safety against the depth at different locations.

Figure 4 provides a visual representation of the liquefaction potential index (LPI) corresponding to different earthquake magnitudes. It is evident from the figure that the LPI values range from a minimum of 21.50 to a maximum of 45.37. These values exceed the threshold LPI value of 15, indicating a significant probability of liquefaction hazard in the region (Iwasaki et al., 1982), (Luna and Frost, 1998), and (MERM, 2003). The range of LPI values, spanning from 21.50 to 45.37, suggests varying degrees of liquefaction susceptibility across the study area. Higher LPI values signify a greater likelihood of liquefaction occurrence and consequently, an increased risk of ground failure during earthquakes.

4 Conclusion

The findings of this research indicate that the region surrounding the Sonahat Bridge, Kurigram is at high risk of liquefaction. The Factor of Safety (FS) analysis revealed that up to a depth of 15 meters from the ground surface, the FS values were below 1, confirming the susceptibility to liquefaction in this shallow layer. Beyond the depth of 15 meters, the FS values fluctuated due to sudden variations in SPT-N values. LPI values for different earthquake magnitudes was found ranging from 21.50 to 45.37. These values exceeded the threshold LPI value of 15, indicating a very high probability of liquefaction hazard in the region. This emphasizes the urgent need for effective seismic risk prediction and hazard management strategies in the Kurigram area. This research provides valuable insights for seismic risk assessment and hazard management in the study area. The results emphasize the critical importance of recognizing and addressing the potential liquefaction risks in the region to ensure the safety and resilience of infrastructure and communities exposed to seismic activities. The results should be utilized in the design, construction and land-use planning processes to mitigate the risks associated with liquefaction.

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